Experimental investigation of axial rupture in a submerged pressure tube

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ABSTRACT

An experimental program was conducted to investigate the physical processes associated with axial rupture in a liquid pressurized tube. Steel tubes, 50.8 mm in diameter and 0.9 mm wall thickness were ruptured in air and water to determine the influence of the pressurizing fluid (water and air) and surrounding liquid on the crack opening characteristics.

The development of the crack opening area during rupture was recorded by high speed photography. Results are presented for the crack opening area history, for crack tip velocity, axial strain near the fracture path, and for the internal depressurization transient.

The results indicate that the surrounding water has a significant effect on the opening characteristics in both the liquid pressurized and the pneumatic rupture cases.

1 INTRODUCTION

Pressure tubes are used to contain and transport high pressure, high temperature fluids. In such an application, the possibility of small pre-existing flaws growing through the wall and propagating axially has to be taken into account.

To predict the consequences of such a failure, the physical processes associated with axial rupture such as fluid depressurization, crack propagation and tube wall deformation must be known. For example, the crack opening rate is the principal factor determining initial energy and momentum fluxes and, hence, the magnitude of forces imparted to adjacent structures during rupture (Baum 1985).

Most of the experimental data available on tube rupture is for a gas pressurizing medium discharging into air. Baum (1982,1985), Emery (1986) and Ives (1974) have investigated axial crack propagation in gas pressurized steel pipes by recording crack tip motion using high speed photography and measuring the internal depressurization transient. These studies provided data to verify analytical models proposed by Baum (1982) and Emery (1982) for predicting the pressure transient, crack opening area development and crack tip velocity.

Published data on pneumatic tube rupture cannot be applied directly to the liquid pressurized case which has fundamentally different depressurization characteristics. To obtain the relevant data for the liquid pressurized tube rupture, an experimental program has been carried out to measure the crack opening characteristics namely the depressurization transient, crack extension rate, crack opening rate and crack tip deformation. The objectives were to determine the effect of using liquid pressurizing and surrounding medium on the opening characteristics.

2 EXPERIMENTAL PROCEDURE

Central to the experimental program was a water-filled cylindrical tank, 1200 mm in diameter and 2100 mm long (Figure 1) in which all the tests were performed. A safety relief was provided to prevent the over-pressurization of the tank, which also had transparent windows for lighting and high speed photography.

Steel pressure tubes (Grade 1010, 50.8 mm in diameter, 0.9 mm wall thickness and 1016 mm long) were held in the explosion tank by end pieces specially designed to prevent leakage and allow easy replacement of test tubes. Axial crack propagation was channeled along a 508 mm long, 40 percent part-through axial defect on the outer surface of the tube (Figure 2). The tubes were dynamically tested by pressurizing to a maximum of 90 percent of the yield stress.

Rupture was initiated by pressurizing until the ligament at the bottom of the defect failed. The loading sequence was as follows: on filling the test loop, the pressurizing fluid was taken to a pressure just below the bursting pressure. The test tube was then isolated by closing the inlet solenoid valve (Figure 1), then the pressure in the accumulator was increased to above the bursting pressure. When the high speed camera was accelerated to a selected speed, it triggered the solenoid valve to open and initiate the tube rupture.

3 INSTRUMENTATION AND DATA ACQUISITION

Photographs of the developing breach were obtained using a HyCam high speed camera. The HyCam has a maximum framing rate of 11000 frames per second. Illumination was provided by a single 2 kW quartz halogen lamp positioned in front of the test piece. To ensure that the camera was running when rupture occurred, the events synchronizing capability of the HyCam was used to trigger the rupture event. Also a single frame recording of the pattern of flow ensuing from the breach was obtained using a 35 mm single lens reflex (SLR) camera with a sound operated shutter release mechanism.

The internal depressurization was measured by piezoelectric pressure transducers (PT-) located in the test loop as indicated in Figure 1; axial strain was measured by two strain gauges (SG-) located in the axial direction along the path of the crack (Figure 2). The test section had to be long enough to allow an adequate period for monitoring the pressure transient before it was disturbed by the leading edge of the depressurization wave returning to the measurement position following reflection from the closed end of the section.

A Nicolet data acquisition system capable of sampling at 1 MHz was used for recording the transient pressure and strain histories. Four channels of 12-bit data word with a memory capacity of 4096 words per channel were used. The data was then transferred to a floppy disk through a 16-bit microcomputer.

4 RESULTS AND DISCUSSION

Figure 3 shows the normalized depressurization history for a typical liquid pressurized rupture into air or water. The speed of the rarefaction wave is given by the distance between the pressure transducers divided by the time interval between the transients.

The pressure transients for the liquid pressurized and pneumatic rupture cases are compared in Figure 4. For air, the sonic speed (345 m/s) is close to the crack tip speed, thus the crack tip is always in a zone of high pressure resulting in a massive breach. Because the sonic speed in water (1350 m/s) is much higher than crack tip speed, there is rapid depressurization hence a limited crack growth.

Table 1 gives a summary of results from four typical experiments. The final crack opening areas and average crack tip speeds are compared for water and air as pressurizing and surrounding media.

Table 1. Crack opening and crack tip velocity

Run	Pressurizing fluid	Surrounding fluid	Crack opening area, mm^2	Crack tip velocity, m/s
4	Air	Air	9052	300
5	Air	Water	3163	240
17	Water	Air	912	90
18	Water	Water	592	62

Lower crack tip speeds and smaller crack opening areas are observed when water was used as surrounding medium because more energy must be expended to overcome the inertia of the denser liquid as the lips of the crack separate behind the crack tip (Hill 1982).

Figure 5 shows typical strain gage records for the liquid pressurized burst. The general axial strain history is in qualitative agreement with those reported by Baum (1985) for pneumatic rupture. The magnitude however is a factor of ten lower reflecting the reduced deformation in the liquid pressurized case.

Figure 6 presents a sequence of high speed photographic records for a rupturing pipe. Taking into account the distortion due to the position of the camera, it is possible to construct a plan view of the opening area for each frame hence determine the growth from frame to frame. In most cases only a few useful frames are obtained because the liquid jet eventually obscures the opening area. The pattern of flow of the jet issuing from the breach is shown in Figure 7.

5 CONCLUDING REMARKS

Failure behaviour of gas and liquid pressurized steel tubes has been sucessfully observed using high speed photography. The failure is initiated by an axial defect.

Gas pressurization results in a massive breach compared to the limited crack growth of the liquid pressurized case.

The surrounding water reduces the speed of propagation and the final crack opening area when either air or water is used as a pressurizing medium.

REFERENCES

Baum, M.R. 1985. Axial rupture of large diameter, gas-pressurized steel pipes. Int. J. Pressure Vessel & Piping. 21:21-48.

Baum, M.R. 1982. The development of the breach generated by axial rupture of a gas pressurized steel pipe. ASME J. Pres. Ves. Techn. 104:253-261.

Emery, A.F. et al. 1986. Axial crack propagation in a pressurized pipe. Proc. ASME Pressure Vessel & Piping Conference.

Emery, A.F. et al. 1981. The use of the split ring model in modeling the axial crack extension in pipes. ASME J. Pres. Ves. Techn. 103:151-154.

Ives, K.D. et al. 1974. Pipe deformation during a running shear fracture in a line pipe. ASME J. Engng. Mat. & Tech. 96:309-317.

Hill, P.G., E.G. Hauptmann & V. Lee 1982. Consequences of pressure tube rupture on in-core components: Phase 1 - Technology Review. Atomic Energy Control Board of Canada Report AECB 34-2-4-17.

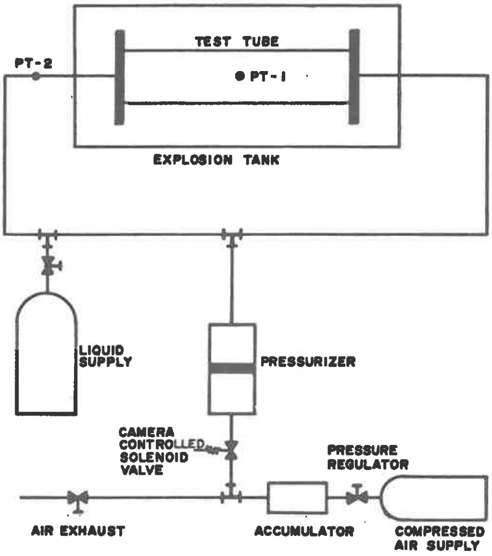


FIGURE 1. SCHEMATIC OF TEST LOOP

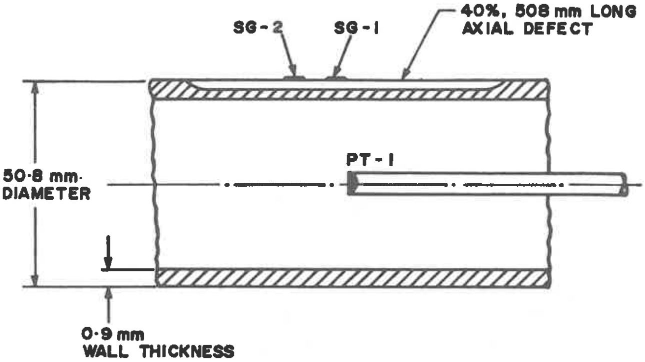


FIGURE 2. TEST SPECIMEN

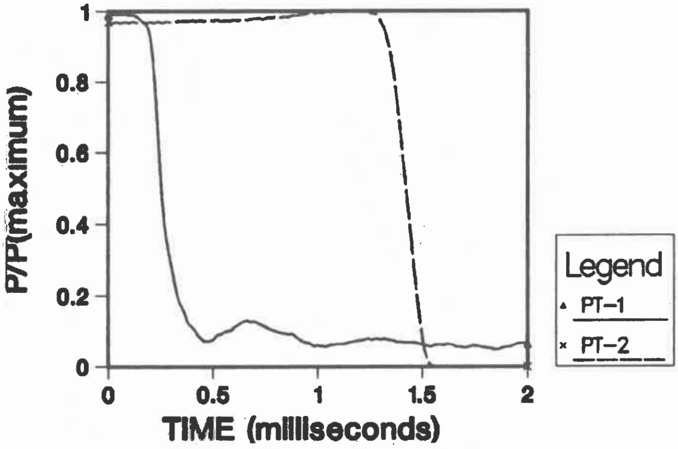


Figure 3. Depressurization transient for water into water

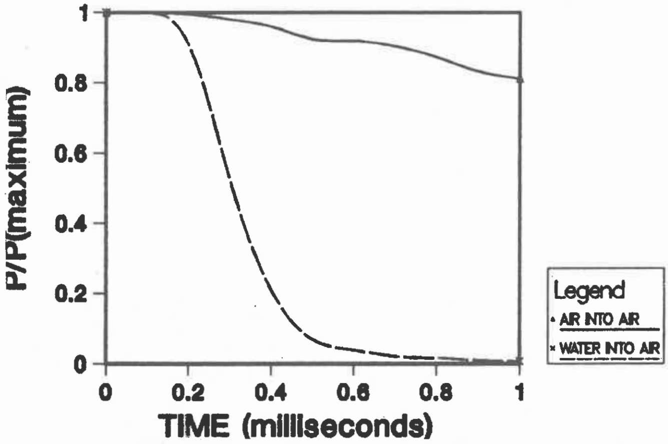


Figure 4. Depressurization transient
(air into air versus water into air)

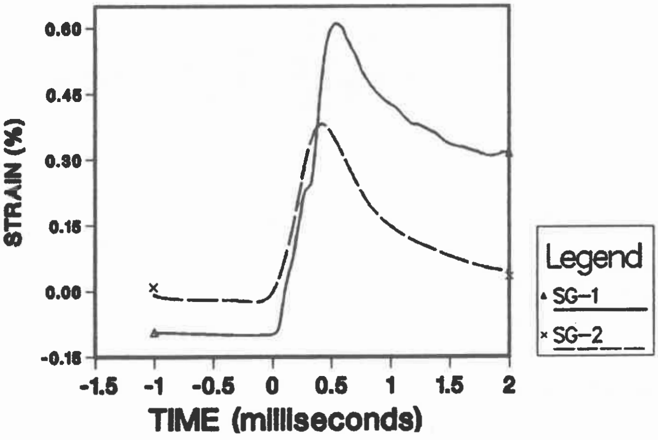
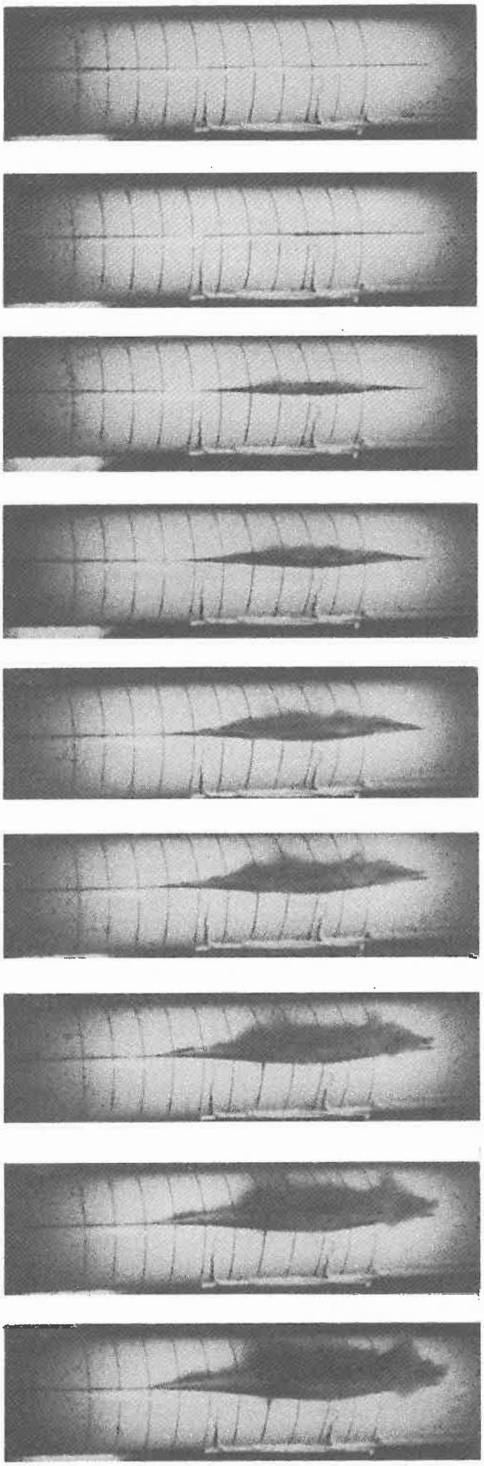


Figure 5. Strain gage record for water into water



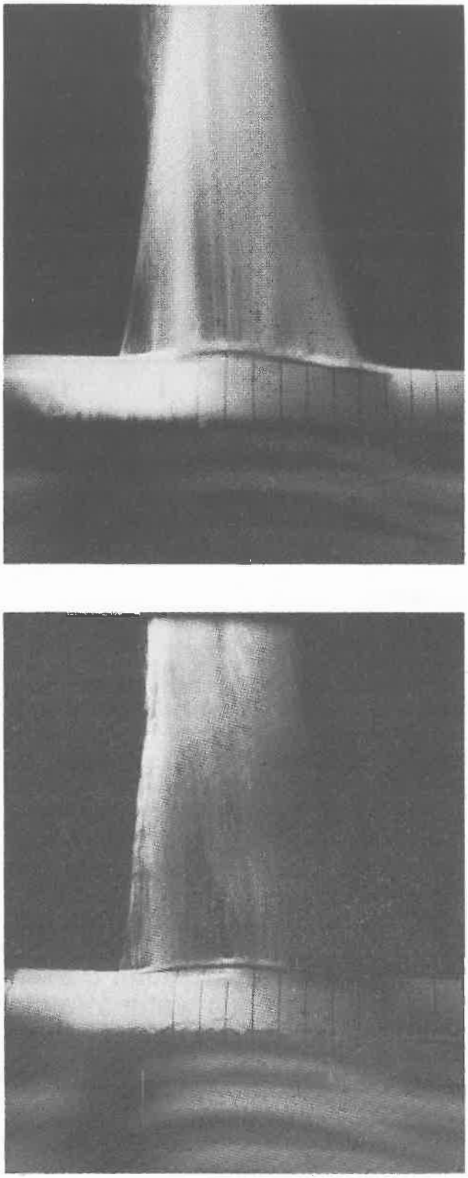


Figure 7. Single frame shots of water jet (water into air). (Shutter speed= 2 msec.)

Figure 6. High speed film of rupture (4500 frames/sec.)